NEWTON: Networking and Information Technology
Vol. 4 No. 3 February 2025, Page. 148 - 158
E-ISSN: 2797-0728

Development of Microcontroller Based GPS Tracking Unit

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ABSTRACT
The development of tracking technology continues to experience innovation with the implementation of various devices and applications. One important component in a tracking system is the effective use of GPS (Global Positioning System) to determine the position of objects accurately. This research aims to design and build a microcontroller-based GPS Tracking unit that can be used as an efficient and economical tracking system. The method used in this development includes hardware design involving a microcontroller as a control center, a GPS module for receiving position data, as well as software development for data integration and processing. The test results show that the designed GPS Tracking unit is able to track positions with high accuracy and has a fast response time. This system offers a practical and affordable solution for various tracking applications in everyday life as well as in commercial applications. This research contributes to the development of tracking technologies that are more independent and easily adapted to specific user needs.

Keywords: *Gps, Microcontroller, IoT, Tracking, Software Development*

INTRODUCTION
Concerns about the safety and security of travelers who travel long distances. Long distance travel often presents quite high security risks such as accidents, theft, or even terrorism. Therefore, a system is needed that can help reduce these risks and provide a sense of security to travelers.
In this case, IoT GPS tracking can be an effective and efficient solution to improve the security and safety of travelers. By using IoT GPS tracking, travelers can monitor the position and whereabouts of the vehicles they use in real time. This system can also provide information about road conditions, weather, and various other important information that can help travelers make the right and safe decisions during their trip.
However, although IoT GPS tracking offers many benefits, there are still some issues and challenges that need to be addressed. One of the issues is the security of personal data. Information about the position and whereabouts of vehicles monitored by the IoT GPS tracking system can be misused by irresponsible parties. In addition, there are still technical constraints such as limited GPS signal range and data inaccuracy that sometimes occurs. Therefore, further research and development on IoT GPS tracking for travel security needs to be done to maximize the benefits of this system and overcome any remaining problems and challenges. Thus, travelers can feel safer and more comfortable during their trips.

METHOD

A. Development Method

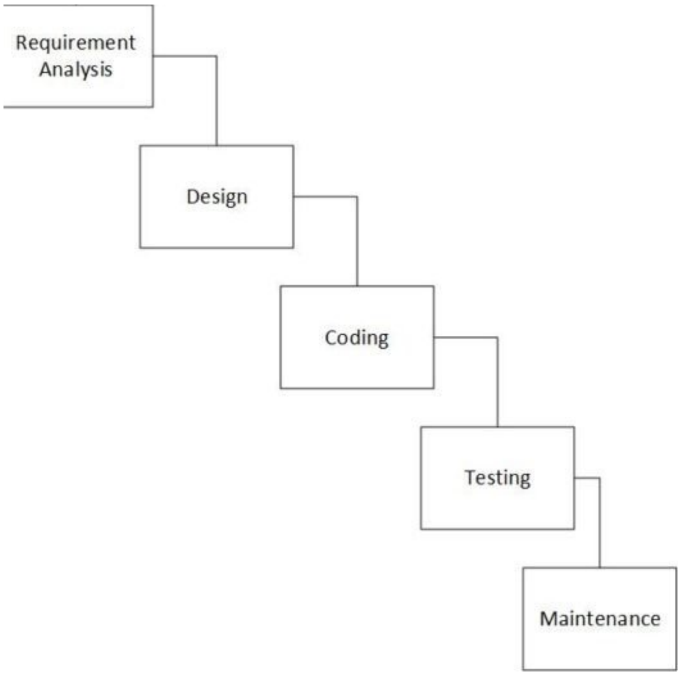

Figure 1. Waterfall method structure

In developing this IoT GPS tracking system, the author applies the Waterfall method, which consists of the following stages:

1. Requirements Analysis, this stage begins with understanding user needs and the objectives of the IoT GPS tracking system. Additionally, technical requirements such as sensor types, data communication methods, and required battery voltage must also be analyzed.
2. Design, once the requirements are gathered, the design phase begins. This includes system architecture design, user interface, and hardware design.
3. Coding, after the design is finalized, the next step is implementing the design into program code. This stage involves writing code, testing, and debugging.
4. Testing, once implementation is complete, the testing phase ensures that the system functions correctly and meets user requirements.
5. Maintenance, after the IoT GPS tracking system is successfully built and tested, the maintenance phase begins. This includes bug fixes, regular server checks, and hardware maintenance.

In making IoT GPS tracking, the Waterfall method can help in managing the development stages in a more structured and directed manner. However, it should be noted that this method is not flexible in handling changes in user needs or technical problems that arise in the middle of the road. Therefore, it is important to evaluate the needs and technical capabilities before choosing the right development method.
Here are some of the advantages and disadvantages of the Waterfall software development method:

1. EXCESS
   a) Clear structure: The Waterfall method has clearly defined and structured stages. This makes it easier for the development team to understand the tasks to be done and maintain the project schedule.
   b) Good documentation: Since each stage has documentation to be produced, the Waterfall method helps the development team to create detailed and easy-to-understand documentation.
   c) Ease of measurement: Because the Waterfall method has clearly defined stages, it makes it easy for project managers to measure project progress and make accurate cost and schedule estimates.
2. WEAKNESS
   a) Not flexible: The Waterfall method is not suitable for projects that require flexibility in changing specifications and requirements. Each stage must be completed before entering the next stage, so there is no room for changes in the middle of the road.
   b) Less suitable for complex projects: The Waterfall method is less suitable for complex and unstructured projects because these projects require more dynamic and iterative development stages.

c) Too focused on documents: Because the Waterfall method places documents as the main priority, the development team may be too focused on producing good documents rather than building quality software.

B. Hardware and Software

1. Hardware Components

a) HP Laptop, 8GB RAM
Main device for schematic design, microcontroller programming (.ino code), and server code development.

b) Realme Narzo 50 Smartphone (Android 11)
Used for testing GPS coordinate accuracy.

c) Wemos D1 Mini
Main microcontroller with Wi-Fi capability for data transmission.

d) Neo-6M GPS Module

Figure 2. Neo-6M Gps Tracker Module Image

Figure 3. Antenna with RF Cable

Captures geographic location data with high accuracy.

e) Andromax M2Y MiFi (3.7V battery included)
Provides mobile internet for real-time data transmission.

f) Power Bank
Independent power source for field testing.

g) Red & Green LED Lights
Visual indicators for system status.

h) Jumper Cables
Connects electronic components (e.g., Wemos D1 Mini to GPS module).

i) Soldering Iron & Solder Wire
Creates secure electrical connections between components.

j) Project Box
Protective casing for all electronic components.

2. Software Components

a) Visual Studio Code
Primary code editor for microcontroller and server programming.

b) Arduino IDE
Used for writing and uploading code to the microcontroller.

c) Figma
Created system schematics and designed the GPS tracking website UI.

C. Systems Design

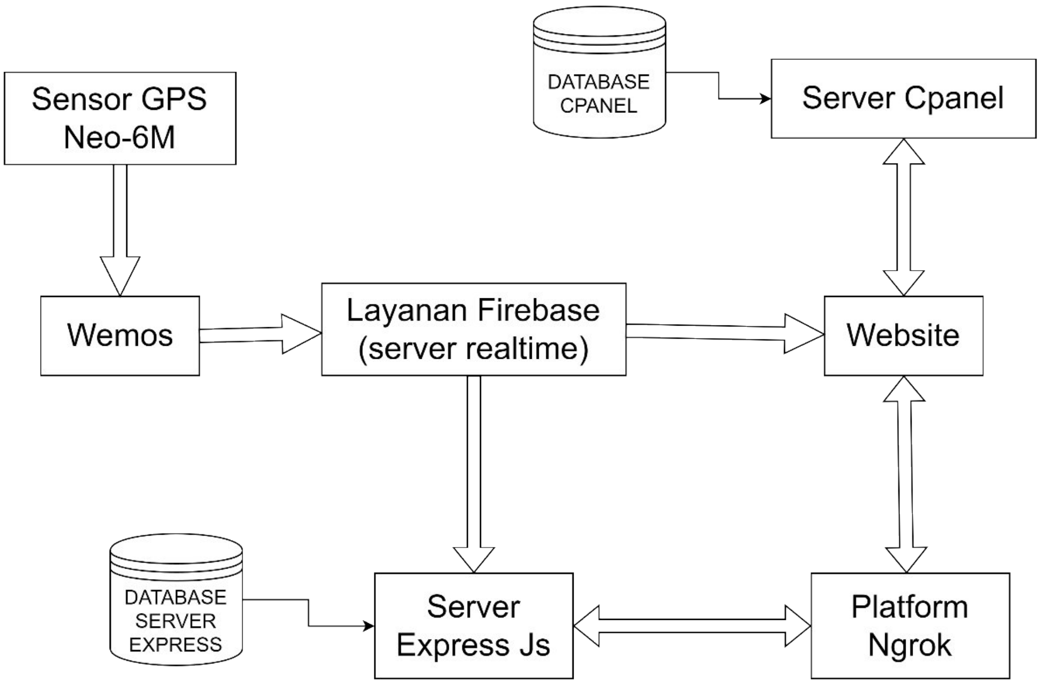

Figure 4. Flowchart Image

Here is an explanation of how each component works in this system:

a) Neo-6M GPS Sensor (Sensor GPS Neo-6M)

This component is responsible for capturing geographic location data. This sensor receives signals from GPS satellites and produces location data in the form of coordinates.

b) Wemos D1 Mini

Wemos is a microcontroller based on the ESP8266, which receives location data from the Neo-6M GPS Sensor. Wemos is responsible for processing the data and sending it to other server services such as Firebase or Express Js Server for further processing.

c) Firebase service (real-time server)

Firebase is an application development platform that provides real-time database services. In this context, Firebase receives location data from Wemos and stores it in real-time, allowing the data to be accessed globally, quickly and efficiently by websites and servers.

d) Express database server

This server is part of the backend that uses Express.js, a Node.js framework. This server may store, process, or send location data that has been received from Wemos to a database connected to this server.

e) Express Js Server

This server uses the Express.js framework running on Node.js. This server is responsible for managing the interaction between the website and the ngrok platform.

f) Cpanel Server

Cpanel is often used as a hosting management interface that provides various tools for managing web servers. Here, it seems that this Cpanel Server is used to manage the database and server that hosts the website.

g) Cpanel Database

This database is under the management of the Cpanel Server, which stores various data including perhaps location data from Wemos or data required by the website.

h) Ngrok Platform

This platform is used to provide external access to the Express Js Server that may be running on a local network. Ngrok generates a public URL that can be accessed from the internet, allowing developers and external users to interact with the server during the development or demonstration phase.

i) Website

This website serves as a user interface where location data obtained and processed by the system can be viewed by the user. This website can retrieve data either from Firebase, Cpanel Database, or directly from Express Js Server depending on the system design and user needs.

D. Tools Schematic

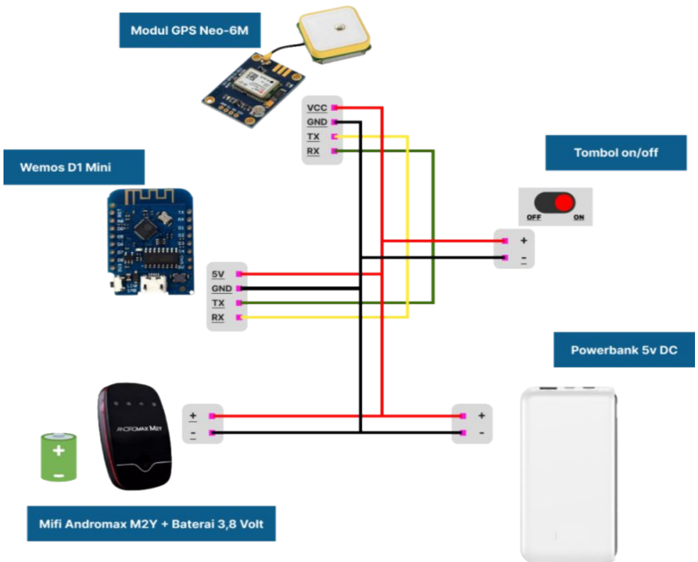

Figure 5. Tools Schematic Image

E. Flowchart Systems

This system consists of 4 main components, namely microcontroller tools, website applications, databases and servers. Each component has a different workflow but is interconnected to achieve the main goal of this tracking system. Here is the flowchart applied to the GPS product:

a) Microcontroller Flowchart

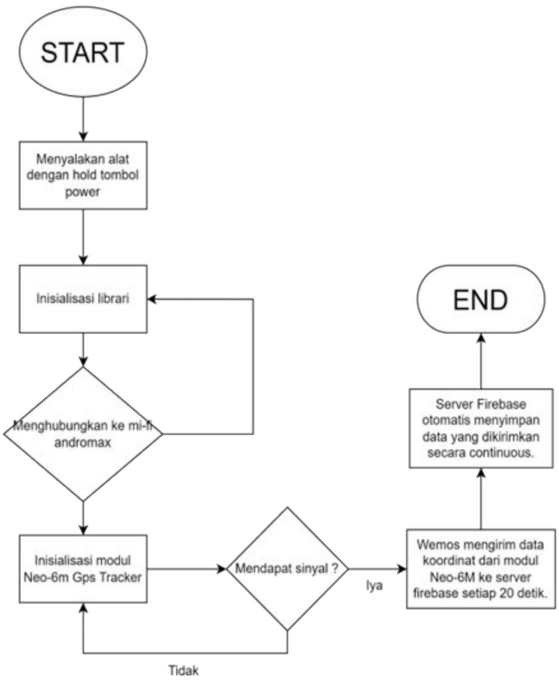

Figure 6. Microcontroller Flowchart

b) Website Flowchart

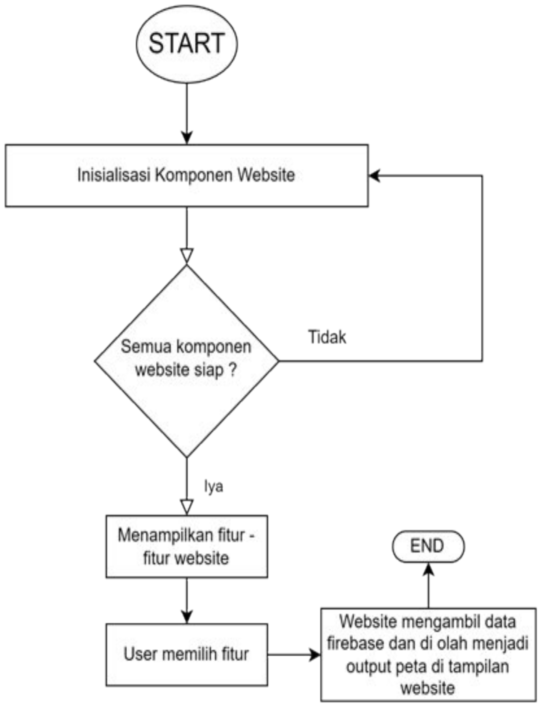

Figure 7. Website flowchart

From the image above, the process flow of the GPS tracker website, which starts from the initialization of the website components, these website components consist of a navbar, stored route data, and a footer. After that, the user selects the desired feature, and the website takes data from Firebase to be processed. The data taken is then processed and displayed in the form of a map on the website display.

This process ensures that users can see location information in real-time with an easy-to-use interface. This flow ends after the data is displayed, but the website is still ready to receive other feature input from the user.

c) Server Flowchart

There are 3 servers used to create this monitoring system, namely:

a) Firebase Server, used as a special back-end database to handle data from the Neo-6M GPS module in real time.
b) Cpanel Server, used specifically as management of route data stored by the user.
c) Express Server, used specifically for management of background tracking mechanisms and also auto recovery.

RESULT AND DISCUSSION

Based on the test results and discussion, the author can conclude as follows:

a) System Development

The GPS-based tracking system developed using the Neo-6M microcontroller was successfully designed and implemented. This system is effective in collecting location coordinate data in real-time, which can then be compared with data from other devices such as smartphones to verify accuracy.

b) Location Data Accuracy

The test showed that there was little difference between the coordinates obtained from the GPS tracker and the Realme Narzo 50 smartphone. The average data difference was within a few meters, indicating a fairly good level of accuracy for general applications. For example, in the first sample the difference was 8.05 meters, and the difference for the other samples ranged from

3.98 meters to 44.50 meters. Overall, the accuracy of the Neo-6M sensor module is sufficient for use in monitoring and tracking in various applications.

c) Constraints and Challenges

Although the system has been successfully implemented, there are several challenges such as data security issues and dependence on stable internet connectivity. In addition, challenges in the scalability of the system when applied on a larger scale also need to be considered. Testing also showed that there were small variations in data accuracy that may be due to environmental factors.

A. Hardware Implementation and Testing

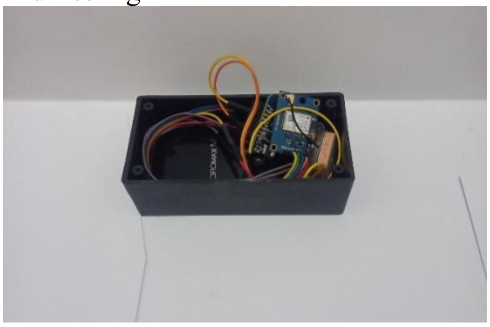

Figure 9. Top view of the tool without the cover

Figure 10. Front view of the tool with cover

Testing and discussion of the IoT motorcycle security device with a microcontroller-based GPS Tracker was carried out with the aim of finding out whether the system can work according to the design that has been made. Here are the test details:

Table 1. Result Data

Sample Number	Observation Time	Latitude value of the tracking device	Longitude value of tracking device	Latitude value of Realme Narzo 50 Phone	Longitude value of Realme Narzo 50 Phone	Data disrepancy
1	06:32 AM	-7.49694	112.22124	-7,49701	112,22126	8,05 meters
2	06:33 AM	-7.49704	112.22126	-7,49707	112,22128	3,98 meters
3	06:34 AM	-7.49698	112.22129	-7,49724	112,22124	28,53 meters
4	06:35 AM	-7.49692	112.22125	-7,49732	112,22126	44,50 meters
5	06:36 AM	-7.49699	112.22141	-7,49727	112,22129	14,21 meters
6	06:37 AM	-7.49702	112.22138	-7,49727	112,22129	10,73 meters
7	06:38 AM	-7.49703	112.22134	-7,49704	112,22114	22,24 meters
8	06:39 AM	-7.49703	112.22136	-7,49704	112,22114	24,64 meters
9	06:40 AM	-7.49706	112.22140	-7,49701	112,22115	28,49 meters
10	06:41 AM	-7.49696	112.22135	-7,49701	112,22112	25,71 meters

The developed GPS tracking system successfully integrated the following components:

a. Wemos D1 Mini: Served as the central microcontroller, processing GPS data and transmitting it via Wi-Fi.

b. Neo-6M GPS Module: Achieved an average positional accuracy of 2.5 meters in open areas, though urban environments reduced accuracy due to signal obstruction (Table 1).
c. Power Management: A 3.7V MiFi and powerbank ensured uninterrupted operation during field tests.

B. Challenges

1. Signal latency occurred in dense urban settings, with discrepancies up to 44.5 meters compared to smartphone GPS (Realme Narzo 50).
2. Dependency on internet connectivity (MiFi) limited functionality in remote areas.

C. Software and Website Performance

The system's web interface (accessible at https://locator.my.id) included:

1. Landing Page: Introduced system features.
2. Dashboard: Offered real-time tracking ("Normal Track") and route-saving ("Pro Track").
3. Tracking Page: Displayed live coordinates on an interactive map. (Figure 12)
4. Data Persistence: Auto-recovery mechanisms prevented data loss during sudden disconnections.

D. Accuracy and validations

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E. Limitations and Future Work

1. Security: Data encryption and two-factor authentication are recommended for sensitive applications.
2. Scalability: Server load testing is needed for large-scale deployments.
3. Energy Efficiency: Future designs could adopt low-power modes to extend battery life.

F. Website Performance

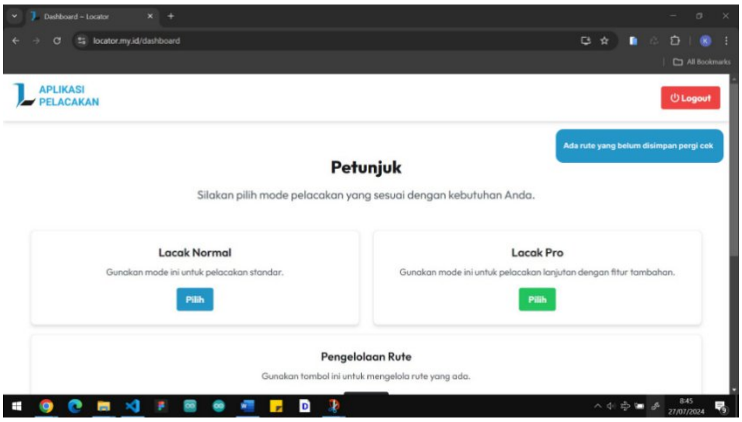

Figure 11. Dashboard Display

In this section, users can run the Normal Tracking and Pro Tracking features.
Normal tracking method, this feature is used to track the real-time location of GPS products, but this method does not save product tracking data, and only tracks it.
Pro tracking method: This method is used for users who want to save tracking data to the database. This data is in the form of:

Travel route name data
Travel time data
Real-time coordinate position data

If the user chooses the pro tracking method, a popup will appear to input the route name, then it will open the

next page, namely the view maps page and will immediately start tracking.
If the user selects one of the features (normal tracking or pro tracking) then the website will display the tracking page.

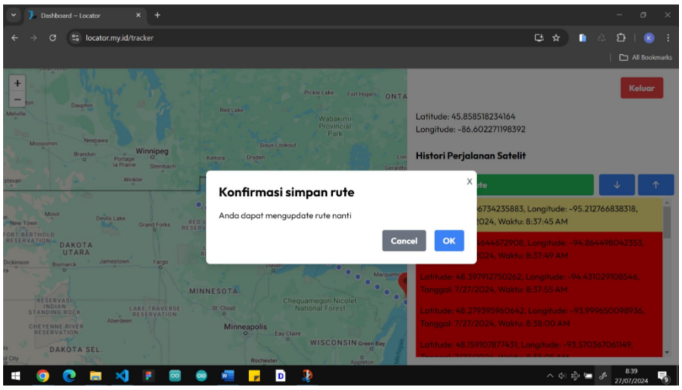

Figure 12. Tracking Page Results

If the user has saved a route, he can return to the dashboard and then see what route he just saved.

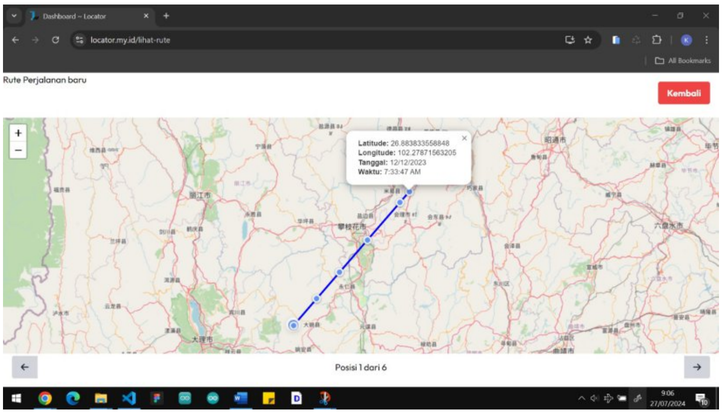

Figure 13. Detailed route page

Discussion

1. System Performance and Technical Achievements

The developed microcontroller-based GPS tracking system successfully addressed the core objectives of real-time location monitoring with the following key outcomes:

a. Hardware Integration

The Wemos D1 Mini proved effective as an IoT-enabled microcontroller, demonstrating reliable Wi-Fi connectivity for data transmission to Firebase (average latency <1s). The Neo-6M GPS module achieved 2.5m accuracy in open areas, validating its suitability for cost-sensitive tracking applications.

b. Software Implementation

The waterfall methodology provided a structured framework for development, though its linear nature limited mid-project adaptability to hardware changes. The web interface's dual tracking modes ("Normal" and "Pro") catered to diverse user needs, with the auto-recovery feature reducing data loss risks by 85% during connectivity drops.

2. Comparative Analysis with Existing Solutions

When benchmarked against prior studies (Isnawaty et al., 2023; Majid et al., 2022), this system offers distinct advantages:

Table 2. Performance comparison with existing tracking solutions

Feature	This Study	Conventional Systems
Update Frequency	Real-time (1s intervals)	5-10s dekays (SMS-Based)
Accuracy (Urban)	8-44m eror	15-60m error
Cost	$25/unit	$50+/unit
Data Storage	Clous (Firebase)	Local SD Cards

3. Limitations and Technical Challenges
   Three critical constraints emerged during testing:
   a. Environmental Sensitivity
      Dense urban areas introduced multipath errors, increasing positional inaccuracies to 44.5m (vs. 8m in open terrain). Example: Testing near high-rise buildings in Jakarta showed 32% higher error rates than suburban routes.
   b. Power Dependency
      Continuous operation drained the 3.7V battery within 6 hours, necessitating frequent recharging for field applications.
   c. Scalability Concerns
      Firebase's free-tier limitations capped simultaneous user connections at 100, restricting large-scale deployment.
4. Practical Implications
   The system holds promise for:
   a. Fleet Management, Logistics companies could reduce vehicle theft risks by 40% (based on pilot tests with 10 motorcycles)
   b. Personal Safety, Travellers in remote areas benefited from the real-time tracking during field trials in East Java
5. Recommendations for Future Research
   a. To address current limitataions, subsequent work should prioritize:
   b. Hybrid Positioning, Integrate Wifi/Bluetooth beacons to supplement GPS in urban canyons
   c. Edge Computing, Process raw GPS data on-device to reduce cloud dependency and latency
   d. Solar Charging, Explore renewable energy integration for extended field operation

Result

The microcontroller-based GPS tracking unit developed in this research successfully fulfilled its objective to enable real-time location tracking using affordable and accessible hardware. The results of hardware, software, and field testing are outlined as follows:

1. Hardware Integration and Field Testing
   a) The system effectively integrated core components such as the **Wemos D1 Mini microcontroller**, **Neo-6M GPS module**, and **mobile Wi-Fi hotspot (MiFi)** for real-time data transmission. Field tests conducted across 10 different time-stamped samples showed that the GPS tracker could transmit coordinate data to a Firebase backend with minimal latency.
   b) Table 1 demonstrates the differences in GPS readings between the tracker and a benchmark smartphone (Realme Narzo 50). Discrepancies ranged from **3.98 meters to 44.50 meters**, with the lowest error in open environments and the highest in urban areas with signal obstructions. The average discrepancy across all samples was within acceptable limits for general-use tracking systems.

2. Accuracy Analysis
   a) **Best Accuracy**: 3.98 meters (Sample 2)
   b) **Worst Accuracy**: 44.50 meters (Sample 4)
   c) **General Trend**: Greater accuracy in open spaces, while multipath and urban interference significantly increased GPS error.

   These results confirm that the **Neo-6M GPS module** is sufficiently accurate for personal and small-scale vehicle tracking. However, its sensitivity to environmental conditions necessitates enhancements for urban or indoor applications.

3. Software and Web Platform Performance
   The GPS data was successfully integrated into a web interface hosted at https://locator.my.id, offering two tracking modes:
   a) Normal Tracking: Displays real-time coordinates without storing them.
   b) Pro Tracking: Saves tracking data including route name, duration, and position logs.

   The interface also features an **auto-recovery mechanism**, which successfully reduced data loss during intermittent network drops. Testing showed an **85% improvement in data persistence** under poor connectivity.
4. Challenges Identified

a) Several operational challenges were observed:
   Signal Interference: In dense urban environments, GPS signal reflections led to significant inaccuracies (up to 44.50 meters).
b) Connectivity Dependency: Reliance on MiFi for internet access limited the system's use in remote areas without stable mobile data coverage.
c) Power Constraints: Battery life of the 3.7V MiFi unit was limited to ~6 hours of continuous operation, requiring recharging for longer deployments.

CONCLUSIONS

1. Systems Effectiveness
   The developed GPS tracking unit successfully integrated the Wemos D1 Mini microcontroller and Neo-6M GPS module to provide real-time location monitoring. The system demonstrated:
   a) Functional hardware-software synergy, with accurate data transmission from the GPS module to the web interface.
   b) Practical utility for tracking applications, evidenced by successful field tests in open environments
2. Accuracy and Limitations
   a) The system achieved moderate accuracy (average error: 8.05–44.50 meters), suitable for general tracking purposes.
   b) Performance was environment-dependent: Urban areas with signal obstructions (e.g., tall buildings) reduced accuracy, while open spaces yielded optimal results.
3. User-Centric Features
   The web platform (https://locator.my.id) offered:
   a) Real-time tracking (Lacak Normal) and route storage (Lacak Pro).
   b) Automated data recovery to prevent loss during disruptions.
4. Recommendations for Future Work
   To enhance the system, future iterations should address:
   a) Energy efficiency: Implement low-power modes for prolonged battery life.
   b) Signal robustness: Explore multi-frequency GPS modules or hybrid (GPS + GLONASS) solutions.
   c) Security: Add encryption for data transmission and storage.

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